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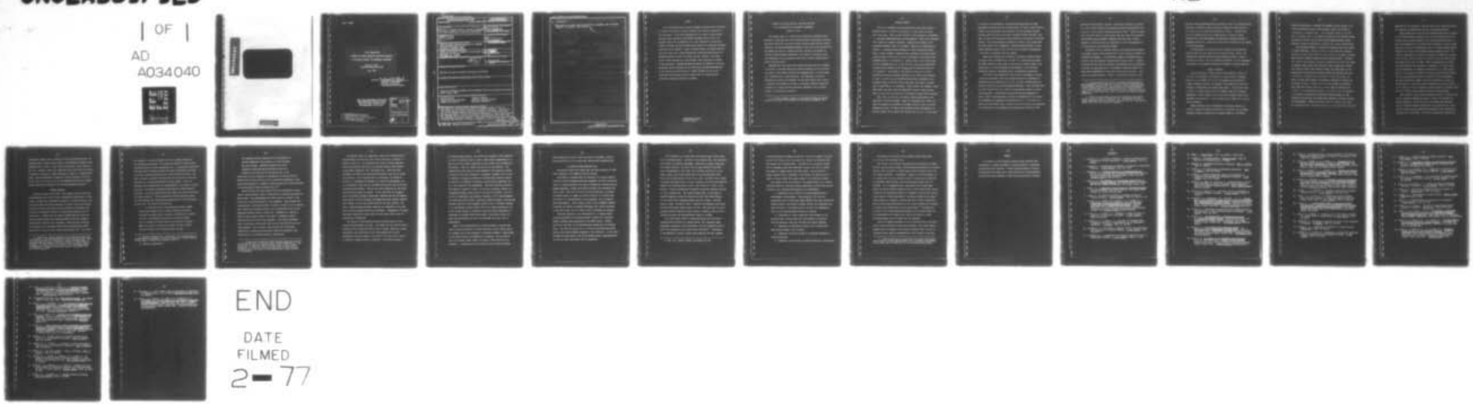

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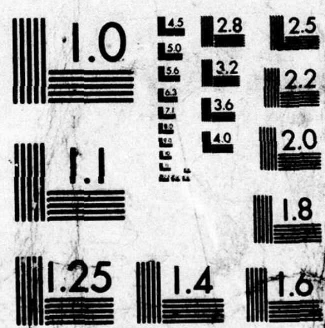

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Staff Memorandum

STUDIES OF COMPLEX BEHAVIOR AND THEIR RELATION TO TROUBLE SHOOTING IN ELECTRONIC EQUIPMENT

Robert S. Czeh
Training Methods Division

June 1957

Approved William A. McClelland
William A. McClelland
Director of Research
Training Methods Division

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This report is a review of the literature concerned either directly or indirectly with the trouble shooting of electronic equipment. Specifically, this review presents the most pertinent findings in the areas of problem solving and concept formation and indicates the manner in which these findings have impinged upon, or could impinge upon, thinking about trouble shooting. The literature on trouble shooting is discussed and the final section outlines a research task designed to develop an efficient, generally applicable

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procudure for trouble shooting electronic equipment, and to develop methods for teaching the procudure.

BRIEF

The relationship between research findings concerned with performance in complex situations and trouble shooting in electronic equipment has been discussed. It has been concluded that the study of human problem solving, concept formation, probability learning, and so forth, has provided little data of immediate use to the researcher in electronic trouble shooting, but has provided certain hints as to important variables which must not be ignored. Various proposed methods of trouble shooting have been noted, and a study dealing with trouble-shooting process and training methods to teach the process has been outlined. The study treats trouble shooting as a generalizable skill which may be studied in the laboratory. Trouble-shooting procedures and methods to teach the procedures will be developed in the laboratory, validated subsequently in the field, and incorporated in a manual designed for use by the combat arms and technical service schools that are concerned with electronic equipment maintenance training.

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STUDIES OF COMPLEX BEHAVIOR AND THEIR RELATION TO TROUBLE SHOOTING IN ELECTRONIC EQUIPMENT

Robert S. Czeh

The present paper is a review of the literature concerned either directly or indirectly with the trouble shooting of electronic equipment. The topics covered in the survey include mainly problem solving, concept formation, and trouble shooting techniques, and a more brief consideration of probability learning, response-sequence analysis, and methods for teaching trouble-shooting techniques. The review is selective rather than exhaustive, but an attempt has been made to choose representative papers from each area.[1]

Specifically, this review will present the most pertinent findings in the areas of problem solving and concept formation and will indicate the manner in which these findings have impinged upon, or could impinge upon, thinking about trouble shooting. The literature on trouble shooting as such will be discussed, and the final section will outline a research Task designed to develop an efficient, generally applicable procedure for trouble shooting electronic equipment, and to develop methods for teaching the procedure.

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1. For more complete surveys of the problem solving and concept formation literature, see Johnson (35) and Taylor and McNemar (57).

PROBLEM SOLVING

The label "diagnostic problem solving" has often been applied to trouble shooting in electronic equipment. In one sense, the label fits rather well. There are the "givens" of the problem--the equipment, the component interconnections, and the symptoms. There is the question--"What causes the symptoms observed?" Insofar as the answer is not immediately obvious, there is a problem. There are two difficulties, however, in defining trouble shooting as a form of problem solving. First, a great variety of behaviors may be defined as problem solving since the limits of the area are very ill-defined; a definition which excludes nothing is no definition. Second, there is the belief among several investigators (e.g., 3, 45, 59) that, given some "systematic" trouble-shooting method, virtually <u>any</u> piece of electronic gear may be troubleshot. This seems to set trouble shooting off from the traditional meaning of problem solving since no writer has attempted to make a case for any one problem-solving method applicable to all problems (except in the very broad sense that, say, Dewey's "method" (12) is applicable to all problems). These matters are, however, pretty much beside the point since the researcher is free to take relevant data from any source and need not be troubled by purely verbal problems.

What, then, has the work in problem solving contributed to our knowledge of trouble shooting? Saupe (51) explicitly set himself the task of bringing the principles of problem solving to bear on trouble shooting in radio, and drew on the writings of such investigators as Duncker, Dewey, Burack, Maier, and Luchins (51, ch. II). On the basis of this work, Saupe derived a trouble-shooting prototype and eight hypotheses concerned with the characteristics of "good" trouble shooters. Several of his hypotheses were confirmed, and his prototype trouble-shooting method was used by the most successful trouble shooters. However, one gets the feeling that Saupe merely paid lip-service to problem solving. His trouble-shooting prototype is stated in very broad terms and could include most "systematic" trouble-shooting methods; the gap between problem solving on the one hand and his method and hypotheses on the other is sometimes very wide indeed.

Gagne (23) discussed two activities, electronic trouble shooting and aerial photo interpretation, in terms of a problem-solving model. The model utilized is very close to the one put forward by Dewey (12); essentially it involves analysis of the "givens" of the situation, hypothesis formation, hypothesis test, and hypothesis elimination.

Recurrent in the literature is the idea that knowledge of certain "facts and principles" about the problem materials are necessary for efficient problem solution (6, 8, 13, 42, 54, 58), and this point has found its way into the trouble-shooting literature. Fattu and Mech (18) had their subjects work on a series of malfunctions placed in a gear-train apparatus. Following this, one group was given magazines to read, a second group was given a lecture on nomenclature of the apparatus components and component interconnections, and a third group was given this same lecture plus a lecture on trouble shooting the apparatus. In a second test on the apparatus, the first group showed the least gain and the third group the most. Saupe (51) found that the scores on a test of basic electronics knowledge correlated significantly with scores on a radio trouble shooting performance test.[2] Saltz and Moore (50) found that "good" trouble shooters knew more about the functional relationships among equipment components than did "poor" trouble shooters, a difference that was independent of both intelligence and of the ability to form abstract concepts.

The effect of set on problem solution has received much attention. For example, Duncker (13) presented data on the detrimental effects of "functional fixedness." More recently, Adamson (1) repeated some of Duncker's work and obtained substantially the same results. Luchins' work (41) with the water-jar problem is well-known, and has stimulated a good bit of experimentation.[3] The general conclusion reached by a great many investigators in this area is that set can be quite detrimental to problem solution. However, no substantial amount of work

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2. Saupe interprets this result as evidence that knowledge of basic electronics is necessary for successful radio trouble shooting. It is possible, however, that both knowledge of basic electronics and trouble shooting proficiency correlate with still a third variable, e.g., learning ability, and that knowledge of basic electronics is not required for trouble shooting. This, of course, is a matter of experimental test.

3. There are some serious grounds for questioning the validity of the water-jar tests as a measure of set. See Kendler (36) for a rather unfortunate series of studies, and Levitt (40) for a devastating review of the test as a measure of rigidity.

has been directly concerned with the effects of set in a trouble-shooting situation, although it would certainly be agreed that "getting off on the wrong track" can slow down malfunction location. Instead, work has been directed toward ways of getting men to continue trouble shooting after non-reinforcement (or possibly punishment) whenever a hypothesis fails (47). (More about this point is included in the section on trouble shooting.)

It would appear that problem solving research has provided few specific facts for the researcher in trouble shooting. Rather, the thinking that inspires problem solving research provides a general framework for much of the trouble-shooting research, and has contributed a few hints as to processes which may be involved in trouble shooting.

CONCEPT FORMATION

Two general types of studies may be differentiated--studies of the order of difficulty of attainment of various types of concepts, such as form and number (9, 29, 32) and studies of the process of concept formation in which some stimulus characteristic is chosen as defining a concept which the subject must learn. In this latter type of study, the subject must learn, for example, that all triangles--regardless of color, height, and so forth--are "correct" and all non-triangles are "incorrect." It is to this type of study that attention will be directed.

Before touching upon the literature in the area, however, it should be noted that trouble shooting can be conceived of as concept formation, albeit a unique type of concept formation. The entire stimulus configuration, including the symptoms and the results of the various checks made by the trouble shooter, defines the concept of "component A is malfunctioning." The uniqueness arises in the fact that the subject creates the stimulus configuration for himself through his method of attack, and that the various defining stimuli, while sometimes present simultaneously, are most often present successively.

The following findings on formation of concepts seem most relevant to trouble shooting. Kendler and Vineberg (38) found that compound concepts are more easily learned if one or more of the simpler concepts which form the compound concept have been learned earlier. Davidson (10) reported that pictures of objects yielded more concepts than names of objects, object-class (more abstract) names yielded more concepts than specific-object (less abstract) names, and manipulation of the experimental materials by the subject yielded more concepts than non-manipulation. Hovland (33) and Hovland and Weiss (34) showed the manner in which both positive and negative instances of concepts aid in concept learning. Hovland and Weiss (34) and Kurtz and Hovland (39) found that concept learning is fastest when all instances of a concept are presented simultaneously, a bit slower when all instances of a concept are presented successively before instances of other concepts are presented, and slowest when instances of various concepts are intermingled. Kendler and D'Amato (37) in a study of the speed of learning reversal and non-reversal shifts, have speculated about the importance of the chaining of implicit verbal cues intervening between the stimulus-card presentation and the card-sorting response.

Since practically no work has been performed with these variables in the trouble shooting situation, one can only speculate about the relation of the various results to the trouble-shooting process. It may be hypothesized that it would be more profitable to teach trouble shooting in terms of the individual parts of a symptom picture before teaching it in terms of the complete symptom complex as such. The "level of abstraction" at which the material is taught will be important; the best that can be said at present is that the level should be neither too low nor too high. Direct participation in trouble-shooting exercises will probably be a necessity. It seems certain that the importance of "negative" information (i.e., check results which do not isolate the trouble but merely eliminate certain components as possibilities) should be stressed for the troubleshooter and that he should be taught to use this information to guide his future behavior. Having the trouble shooter write down the results of all checks, to keep as complete a symptom picture as possible before him at all times, will probably facilitate trouble shooting.

Note should be taken, before leaving this topic, of fairly recent work in applying communication theory to some of the problems in concept formation. Miller and Frick (43), drawing upon Shannon's work at the Bell Telephone Laboratories, have shown how the "uncertainty" associated with predicting the subject's next response in a sequence may be determined. The factors entering the computations include the (usually short) sequence of stimuli presented earlier, the responses made to these earlier stimuli, the knowledge of whether these responses were "correct" or not, reward probability, and the subject's set, etc. Hovland's paper (33), mentioned above, dealt with the effects of positive and negative concept instances in terms of a communications model. Other interesting and important work has appeared (2, 14, 15, 16, 20, 28, 31, 52, 53), but it is not immediately obvious how communication theory can be applied in the trouble-shooting situation.[4]

TROUBLE SHOOTING

The work in this area has been of two types; there has been some experimentation and a good bit more "enlightened" speculation. Miller, Folley, and Smith have published two reports on trouble shooting. The first (45) dealt with trouble shooting to chassis and to parts within chassis; the second (46) dealt with the problem in the special case in which all components (chassis or stages within chassis) lie in a series chain. Neither the more general trouble-shooting method nor the more specific half-split technique seems to have been compared experimentally with any other technique. Warren and his associates have developed the Generalized Electronics Trouble-Shooting (GETS) Trainer and a course in basic trouble shooting (48, 59). The trainer

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4. Knowing the stimulus sequence alone reduces the uncertainty of prediction, as has been demonstrated by Hake and Hyman (31). Therefore, some application of the theory to trouble shooting should be possible given the complete malfunction history of a given piece of equipment. For what seems to be a start in this direction, though not explicity in terms of communication theory, see Detambel (11) and Stolurow _et al._ (55).

was designed to simulate problems met with in trouble shooting to the malfunctioning chassis. The course was derived from the trouble-shooting protocols of three experienced men. An unpublished experiment[5] with high school students has shown that both intelligence and amount of practice influence proficiency in trouble shooting the GETS. However, the value of neither the course nor the trainer has as yet been evaluated in a military maintenance training program. Rulon and Schweiker (49) developed sets of "diagnostigrams" to be used in conjunction with a "backtrack" trouble-shooting method by flight simulator mechanics. Rulon has indicated that the course built around the method was quite successful.[6] The K-System MAC-1 Trouble-Shooting Trainer (21) has recently been evaluated experimentally with very encouraging results (22). The authors concluded that:

> ". . . for both the written and performance measures immediately after training, and in terms of measures obtained in the field six months later, the group of trainees who received all their trouble-shooting practice on the MAC-1 Trainer show no evidence of having received less effective training [than the group of trainees who received all their trouble shooting practice on the K-System bench mock-up] . . . .

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5. Personal communication. Phone call to Dr. Joseph Tucker at the Maintenance Laboratory, Air Force Personnel and Training Research Center, Lowry Air Force Base, Colorado, 9 Apr 57.

6. Personal communication.

> The experiment further demonstrates the feasibility of separate instruction and practice in trouble shooting the entire system. Apprentice mechanics can learn systematic trouble-shooting procedures based on an analysis of the data flow of the system" (22, p. 39).

Success has also been reported in teaching men to trouble shoot by methods which had been found to lead to successful performance on the Trouble-Shooting Board, a symbolic trouble-shooting test device developed for testing guided missile personnel (24, 27).[7]

Saltz and Moore (50) have observed that the performance of unsuccessful trouble shooters tends to deteriorate as failures (non-reinforcements) mount. They hypothesized that this occurs as a result of the extinction of approach responses to the equipment. They reasoned that requiring men to pre-plan the manner in which a trouble is to be attacked would offset the extinction effects, and an experimental test of this hypothesis yielded positive results (47). Berkshire (3) reported a study in which trouble shooters were given a "cookbook" trouble-shooting manual and color-coded schematics. The printed procedures were of such great effectiveness that not even one man used the color-coded diagrams. The "cookbook" contained what may be described essentially as primitivized performance check-out procedures, with instructions to be followed whenever a check failed.

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7. Several other "symbolic" trouble-shooting tests have appeared, such as the Tab Test (7), the MASTS (30), and the AUTOMASTS (4). The possibility of using the tests as trainers seems to have remained unexplored. It should be noted that these tests are quite similar, differing only in the manner in which information is made available to the examinee.

The nearest thing to a comparative study of the effectiveness of various methods in radio and radar trouble shooting is included in a report by Bryan (5). He categorized the "initial attack sequences" (first five actions) used by men in trouble shooting radio problems on the MASTS, AUTOMASTS, and a job-sample test. There were five categories so defined that nontechnical personnel were able to assign the protocols. The categories were (a) half-split, (b) middle-to-trouble, (c) loudspeaker-to-antenna, (d) antenna-to-loudspeaker, and (e) unsystematic, which may have included some men who used probability trouble-shooting methods. The men were quite consistent in the method they used from trouble to trouble. It was found that use of <u>any</u> of the four systematic methods located more troubles than did the unsystematic method, and the half-split and middle-to-trouble methods required fewer checks to locate the trouble than did the other methods. The radar trouble-shooting protocols could not be categorized in the same manner, and new categories had to be developed. Assignments to category were quite subjective in many cases, and the radar results were not particularly illuminating.

The various trouble-shooting methods mentioned appear to have several characteristics in common. All assume that the trouble shooter possesses certain supportive skills such as vision, olfaction, tactual sensitivity, and the ability to use test equipment and to make adjustments and minor repairs. These skills are used first to obtain as complete a symptom picture as possible. In trouble shooting to the malfunctioning chassis, the system block diagram is then consulted in order to determine points at which checks and/or adjustments may be made so that each action eliminates as many chassis from consideration as possible. (This is, indeed, the crux of all the methods.) The system block in each case is traced backwards, from outputs to inputs, to points of data-flow divergence, convergence, feedback, and so forth. The ability to recognize parallel but qualitatively different outputs of chains to an indicator is essential and often gives important cues as to the location of the malfunction. Half-split checking procedures (the making of "general" checks, and then more "specific" checks) are recommended wherever series chains of chassis are involved. Use is to be made of probability data whenever available, and of such procedures as writing down check results, switching identical chassis, and comparing readings obtained on test equipment against lists of required readings. It is interesting to note, however, that in no method proposed for use by the trouble shooter to chassis is there any stated requirement for knowledge of so-called "basic electronics," and Miller, Folley, and Smith (44) specifically exclude such knowledge from their list of requirements.

Many of the characteristics of trouble shooting to chassis seem also to be characteristics of trouble shooting to parts within chassis. For example, use of test equipment is obviously required. Backtracking on the chassis blocks and schematics is necessary. The man must be alert for strange sounds, smells, and similar indications from the equipment. A possible point of difference is that trouble shooting within chassis may require "basic electronics" knowledge, although this possibility has by no means been substantiated experimentally.

A PROPOSED TROUBLE SHOOTING TASK

The present section will expand upon the Task statement for Task TRACE contained in the HumRRO FY 58 work program.

Task TRACE is concerned with the discovery of efficient general methods of trouble shooting electronic equipment, and with the specification of training methods to be used in teaching the trouble-shooting methods developed. Miller and Folley's criteria for efficiency (44) will be used. These are (a) time to locate malfunction, (b) number of discrete steps, or number of abortive choices, (c) training time and effort, (d) transferability to new equipment, and (e) capacity level requirements. Other criteria, such as error distance, pattern of search, and extent of response stereotype (17), will be utilized as the need arises, and new criteria will be developed if necessary.

The basic approach to the investigation is to study trouble-shooting procedures and training methods as applied in a miniature system, possibly some modification of the GETS Trainer. Trouble shooting to the level of the malfunctioning chassis will be attacked first. The task will begin with an a priori trouble-shooting method based on the various methods presented in the literature. As the study proceeds and weak points in the method become obvious, experimentation to fill out these weak points will be undertaken.

A few comments are in order about the approach *via* a device rather than an existing system. According to one analysis (19), the maintenance job consists of checking, adjusting, replacing, servicing, repairing, and trouble shooting. The first five of these behaviors very often occur independently of each other and of trouble shooting, as in the daily, weekly, and monthly checks made at the organizational level. When trouble shooting must be done (e.g., when a specified daily, weekly, or monthly adjustment fails to clear a symptom), the first five behaviors support the trouble-shooting process; they function as "tools" in the process. Trouble shooting may be defined as data-flow analysis utilized to locate malfunctions. The trouble shooter must, on the basis of observed symptoms, choose the appropriate block (data-flow) diagram. He must decide which components might cause the trouble, and what checks to make. He must be able to interpret the meaning of the checks and must decide what further action to take. Each check and its interpretation should eliminate as many chassis as possible until, by this iterative process, the malfunctioning chassis is located.

It is the present writer's working hypothesis that the task of teaching parts location in a complex system, test equipment usage, adjustment procedures, repair procedures, and other supportive skills, while time consuming, is not particularly difficult.[8] Accordingly, it was decided to utilize a device which minimizes the time required

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8. See, e.g., Glaser, Glanzer, and Murphy (25, 26).

to teach the skills by making the various actions very simple to perform. Another factor which led to the choice of a device was the desire that the research not be system-bound. Data-flow in the "miniature system" will be completely under the researcher's control and will be variable from simple to complex within very wide limits. The data-flow of complex systems will be reproduced on the device, and subjects will be taught to trouble shoot the complex systems in the miniature setting.

The purpose of this first phase of the research then, is to develop efficient methods of teaching efficient procedures for data-flow analysis. At present, the following experimentation is contemplated:

1. Comparison of the effects of teaching-symptom-cause vs. cause-symptom relationships. Stolurow et al. (56) have non-experimental data on this point which indicate that some occasionally sizable negative and positive transfer effects occur depending upon both the nature of the training and of the job, but experimental work in the trouble-shooting situation is lacking.

2. Comparison of a group taught data-flow analysis on the equipment with a group taught data-flow analysis in isolation from the equipment using only the data-flow (block) diagrams.

3. Comparison of individuals working on the troubles with small groups working on the troubles.

4. Comparison of various methods of critiquing individual or group performances.

5. Comparison of proficiency of groups differing in intelligence.

This phase of the research will probably utilize high school students from the Washington area.

The results of the various experiments will eventually be brought together and the entire package, trouble-shooting procedures and training methods, will be applied to several Army courses training for 1st and 2nd echelon electronic maintenance. Because of the time element, it is probable that only one section of several courses will be modified or relatively small systems, such as surveillance radars, will be utilized. It is contemplated that comparisons will be made among groups trained by whatever method is then in use in each school, groups trained by the experimental method but composed of men who have had the usual course in "basic electronics," and groups trained by the experimental method but composed of men who have had no "basic electronics." The non-trouble-shooting sections of the courses involved will probably be taught using methods then in use in the school.[9] Following this evaluation, the trouble-shooting procedures and training methods will be incorporated into a manual to be used by the schools in their training programs, and the manual will be evaluated.

When it is deemed profitable to do so, attention will be directed toward trouble shooting to parts within chassis. This work, however, depends upon the findings of the research outlined above, so that no statements about possible experimentation will be made at this time.

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9. There is the distinct possibility that results from United States Army Air Defense Human Research Unit's proposed Task MAINTRAIN will be drawn upon as needed for the non-trouble-shooting topics.

SUMMARY

The relation of the findings in various areas concerned with performance in complex situations to trouble shooting in electronic equipment has been discussed. Various proposed methods of trouble shooting have been noted, and a study dealing with trouble-shooting process and training methods to teach the process has been outlined.

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